

Fabrication and Test of Poly-Crystalline Diamond Piezoresistive Position Sensors for Cochlear Implant Probe

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Abstract

This paper reports on the application of high-sensitivity poly-crystalline diamond (poly-C) piezoresistive position sensor in implantable cochlear probe for the first-time. The fabricated poly-C sensor, demonstrating a successful integration of diamond and silicon-based microsystems technologies, leads to a high intra-grain gauge factor (GF) of 28. The film quality, electrical properties, contact resistance and piezoresistivity of the poly-C sensors are characterized to study the dependence of GF (from 8 to 70) of poly-C on the fabrication conditions. As the reported GF values for poly-C are in the ranges of 7 – 120 [1] and 3000 – 4000 [2] for inter- and intra-grain piezoresistors, respectively, the use of poly-C sensors in microsystems is expected to lead to unprecedented applications.

POSITION SENSOR FOR COCHLEAR PROBE

Cochlear prostheses have been used as a hearing enabling technology to help over 100,000 profoundly deaf people by electrically stimulating the cochlear nerve cells with the implanted electrode. The ability to measure electrode curvature and position can greatly improve the prostheses performance by minimizing any damage to the cochlea as the probe is inserted and achieving better signal delivery [3]. While poly-Si piezoresistive sensors have been used in microsystems, poly-C sensor was explored in this study due to its high sensitivity using a 12-mask fabrication process employing surface and bulk micromachining techniques. Poly-C is an excellent sensor material especially at high temperatures and in harsh environments due to its large band gap, and its excellent physical and chemical properties. This paper reports a new application of the poly-C thin film as a high-sensitivity piezoresistive position sensor fabricated and tested for an implantable cochlear probe.

FABRICATION AND TESTING

The details of typical probe fabrication process are described elsewhere [3]. A cross-sectional diagram of the cochlear probe is shown in Fig.1 (a) to illustrate the integration of poly-C sensors using the 4th mask. Diamond-powder-loaded water (DW) was spun on top of silicon nitride dielectric layer to provide the seeding for poly-C thin film growth by microwave plasma chemical vapor deposition (MPCVD). Poly-C film was patterned using electron cyclotron resonance (ECR) assisted plasma etching process as shown in Table 1. A metal stack consisting of Ti/TiN/Al/Ti was used as the interconnect layer between poly-C sensor and poly-Si wire with a contact resistivity of 10^{-3} - $10^{-5} \Omega \cdot \text{cm}^2$ between poly-C and Titanium. SEM, AFM and Raman spectra were used to check the quality of poly-C and optimize the fabrication process. Fig.1(b) shows SEM pictures of the released structure with poly-C position sensors.

For testing, the probe backend was glued on a substrate and got electrically connected by gold wire bonding. Strains, applied on the probe by bending the 4 μm thick probe into different curvatures, were calculated from corresponding curvature radius and probe thickness (Fig. 2(a)). More poly-C test structures were fabricated on oxidized silicon wafers to optimize the seeding densities, sensitivities and to study the intra-grain GF. Another seeding method, diamond-power-loaded photoresist (DPR), was used to study the GF variation. Fig.2 (b) shows the dependence of poly-C film GF on resistivity and grain size. The small grain (0.2 μm) and large grain (0.6 μm) films were fabricated using DW and DPR seeding methods, respectively. The result shows that large grain size and high resistivity help improve the GF from 7 to 70, but may cause problems related to contact resistance and surface roughness. Further study of integrating intra-grain piezoresistors in the probe is expected to increase the sensitivity substantially [2].

Table 1. Poly-C fabrication & etching parameters

Poly-C deposition using MPCVD		Poly-C dry etching	
H ₂ /CH ₄ Gas flow (sccm)	200/3	O ₂ /SF ₆ /Ar Gas flow (sccm)	28/2/6
Trimethylboron doping (sccm)	0.2 - 2 x10 ⁻³	Microwave power (W)	400
Microwave power (kW)	1.6 - 2.4	Pressure (mini-torr)	4
Gas pressure (torr)	22 - 45	RF power (W)	100
Substrate temperature (°C)	520 - 780	RF bias voltage (V)	-150
Deposition rate (μm/hr)	0.1 -0.3	Substrate temperature(°C)	< 50
Film thickness (μm)	0.6-1	Etch rate (nm/min)	120

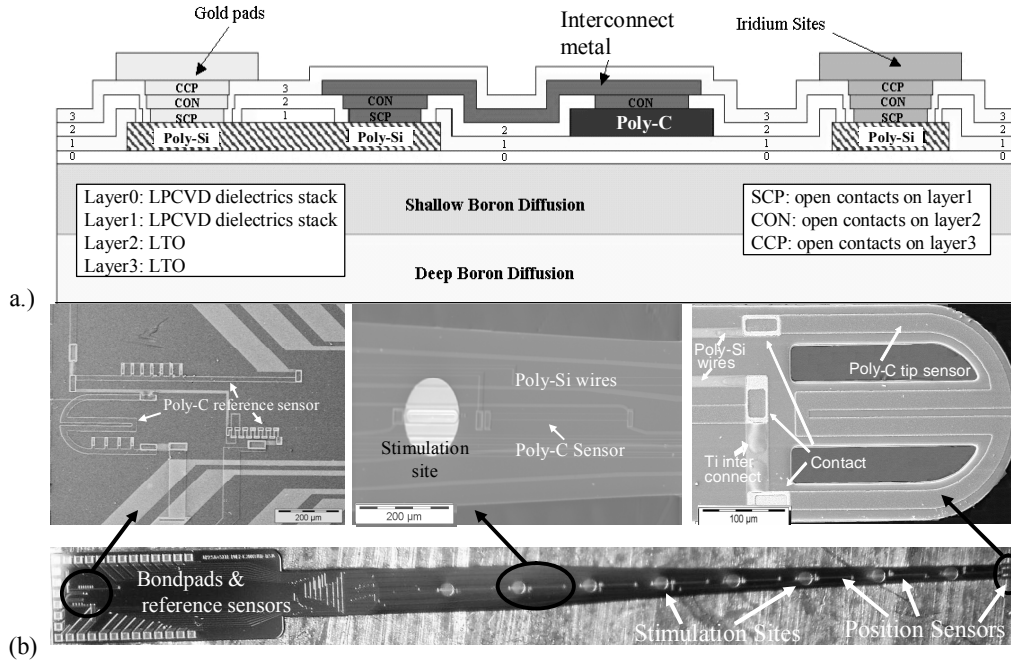


Fig. 1 (a) Layer description for the cochlear implant probe with poly-C strain gauges, (b) SEM of the cochlear implant probe with poly-C piezoresistive position sensors.

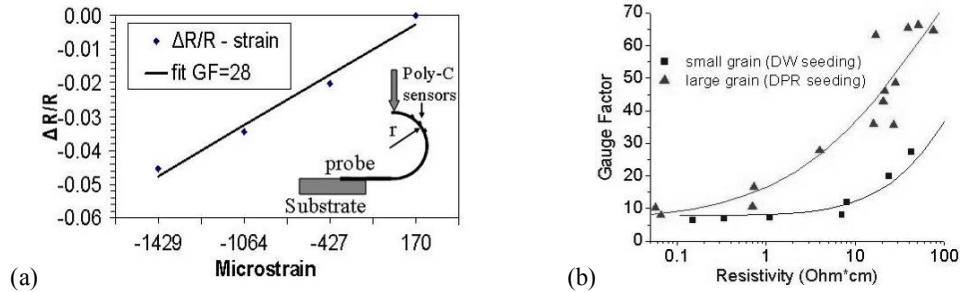


Fig. 2 (a) Testing structure of probe position sensing and the gauge factor result, (b) Relation between the poly-C GF and the boron doping level for DPR and DW seeded films.

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